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S. A. CHAPLYGIN AND WING LIFT

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16. Abstract

The history of the development of the laws of flight is reviewed. The study begins with the works of Isaac Newton, discusses the contributions of Stokes, Helmholtz, and Rayleigh and concludes with the research of S.A. Chaplygin.

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S. A. CHAPLYGIN AND WING LIFT

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The history of the discovery of the laws of flight is one of the most dramatic stories in science. People observed the flight of birds for centuries but prior to the beginning of the present century it was still not clear why birds with their low forces and low energy levels are able to perform long-distance flights at very high speeds.

The first theory of the forces acting on a body during its motion in a gaseous medium was that of the creator of classical mechanics Isaac Newton. However, later calculations and observations showed that his theory does not explain the possibility of flight (excessively high drag with low lift force). In the 18th century Euler constructed the ideal (inviscid) fluid model and gave a mathematical description of its motion. It followed from his theoretical views that in the case of uniform movement of a solid body in an unbounded, vortex-free ideal-fluid stream the resultant of the forces applied to the body is equal to zero. This also obviously contradicted experience and, as was correctly surmised, was a consequence of the assumption that vortices and vortex surfaces are absent in the fluid. On the other hand, it was shown that in a homogeneous inviscid fluid

* Numbers in the margin indicate pagination of original foreign text.

vortices cannot develop in a potential force field. Thus a sort of vicious circle developed.

In the course of the 19th century the questions of the forces which arise with motion of solid bodies in a fluid was studied by such outstanding physicists as Stokes, Helmholtz, Kirchhoff, Thomson, and Rayleigh. They made great contributions to hydrodynamics but the flight problem still remained unresolved.

Toward the end of the 19th century it became clear that flights would soon be accomplished by heavier-than-air vehicles and in 1903 the Wright brothers actually made their first flight. By that time many experiments had been conducted to determine the lift and drag forces (Lilienthal, Penaud, Langley, and others). However, the nature of the lift force was still not clear and the airplane wing was not amenable to calculation.

Today the study of liquid or gas flow around solid bodies, determination of the forces acting in this case, finding the optimal shape of airplane wings, airscrew blades, compressor and turbine blades, and so on constitute a vast independent field of mechanics — aerodynamics. The theory of wing lift forms the basis of aerodynamics.

The primary factor in creating the fundamentals of aerodynamics was the understanding that in the case of flow around bodies of special shape (wings) under the influence of the viscous forces there can be established a special circulatory flow which is extremely close to ideal-fluid flow. This circulatory flow gives rise to a lift force and vortex system. In this case the drag forces due directly to the action of viscosity may be very small. Viscosity causes the flow to change significantly only in a very thin "boundary layer" at the surface of the body. Of decisive importance was theoretical study of the limiting case of uniform motion of a cylindrical wing of infinite span in an ideal fluid stream. For a special form of such a wing (indicated by Chaplygin) a lift force develops with zero drag.

Two outstanding Russian scientists played a major role in discovering the secret of flight and creating the bases of aerodynamics: Zhukovskii and Chaplygin. Bonded together by friendship and commonality of scientific interests but guided by their individual talents and natures they followed their own paths in the field of science. However, in the critical period when the nature of the wing lift force was discovered the studies of Zhukovskii and Chaplygin were intimately related and supplemented one another.

Of greatest importance were Zhukovskiy's study entitled "Bound Vortices" [1] and Chaplygin's paper entitled "Pressure of Plane-Parallel Flow on Obstructing Bodies (on the theory of the aeroplane)" [2] which was presented to the Moscow Mathematics Society in February, 1910. In this paper Chaplygin rediscovers the expression for the lift force in terms of flow circulation which was obtained earlier by Zhukovskiy. The most notable feature of this study is the statement that if the wing profile has a rounded leading edge and sharp trailing edge then as it moves uniformly in a fluid a circulatory flow is established with continuously shedding flow at the sharp trailing edge. In this case a lift force proportional to the angle of attack develops. Further experiments showed how such flow is established and made the Chaplygin hypothesis almost completely obvious. In this way a new fundamental wing shape characteristic was discovered.

We cannot say that Zhukovskiy and Chaplygin did not have predecessors. The development of a lift (side) force acting on rotating spherical cannon balls in the plane perpendicular to the flight velocity vector was established from analysis of cannon firing in the first half of the 18th century [3]. The remarkable study of Magnus [4] appeared in 1853, in which his experiments on measurement of the side force which arises in flow of a wide stream past a rotating cylinder were discussed. In this study he explained how the side (lift) force arises in circulatory flow.

As the cylinder rotates a rotational (circulatory) flow gradually develops which is superposed on the main flow. On the side where the velocities increase when combined the pressure on the surface of the cylinder decreases and on the opposite side, where the velocities decrease, the pressure increases. In this way the side force develops.

Figure 1. Sergey Alekseevich Khristianovich, director of the laboratory of the Institute of Problems of Mechanics of the Academy of Sciences of the USSR. Specialist in questions of aerodynamics and gasdynamics

A study of Rayleigh [5] was published in 1877 in which he used the ideal fluid model to calculate the lift force for circulatory flow around a cylinder (Magnus flow), and in this particular case he obtained the general Zhukovskiy theorem which was to be established later. In 1902 Kutta published a study [6] in which he solved the problem of continuous ideal fluid flow around a wing where the wing represents part of the surface of an infinite circular cylinder. If the flow velocity is parallel to the wing chord we can find a circulatory flow which flows smoothly around the sharp edges of the wing. The lift force which arises in this case was again calculated.

Zhukovskiy's remarkable theorem expressing the lift force in terms of flow circulation was established in 1906.

However, all these studies were still not related with the theory of flight. This association was made only after the appearance of the previously mentioned study of Chaplygin entitled "Pressure of Plane-Parallel Flow on Obstructing Bodies (on the theory of the airplane)", the study of Zhukovskiy entitled "Airplane Lifting Surface Contours" [7] and still another study by Kutta [8].

In a lecture entitled "Results of Theoretical Studies of Airplane Motion", Chaplygin presented in popular form, referring to preceding studies, the contents of his remarkable work and data on the possible pattern of flow around a wing of finite span.

Only a few years later the vortex theory of the finite-span wing was developed in definitive mathematical form by Prandtl for the airplane wing and by Zhukovskiy for the propeller blade.

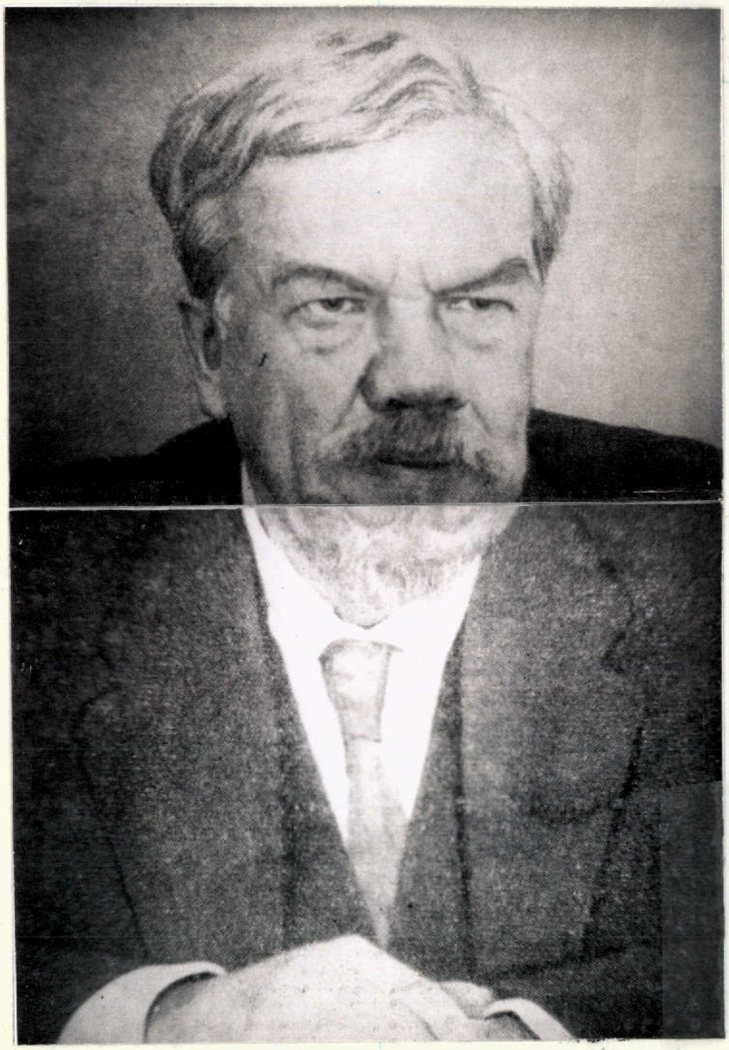

Figure 2. S. A. Chaplygin in his days as leader of the seminar of the general theoretical group of TsAGI (1935-1940)

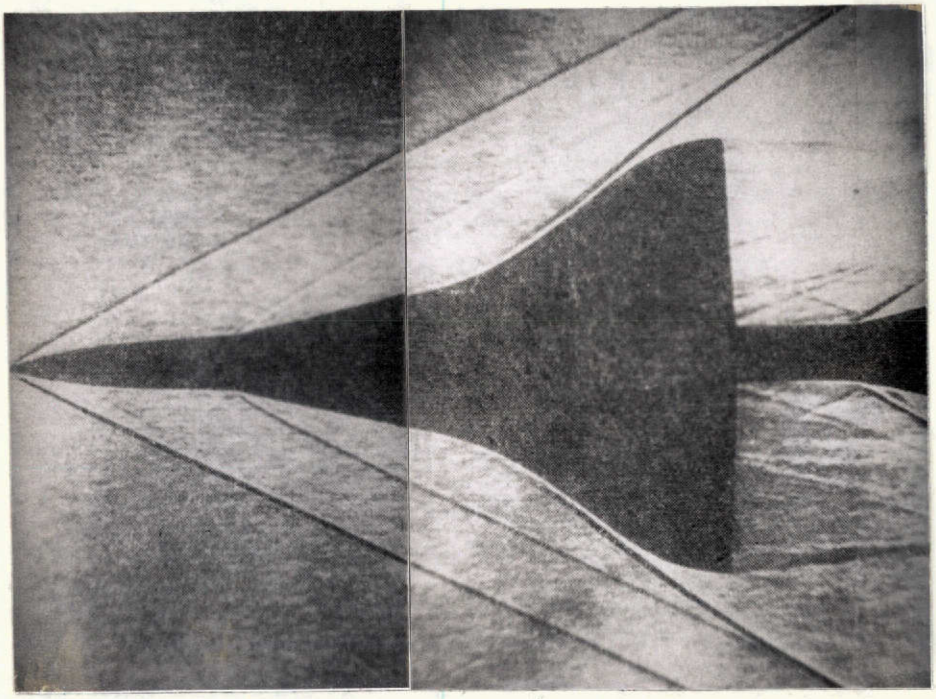

Figure 3. Supersonic flow around airplane model

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